

Universal MEMS Seismometer

Completed Technology Project (2018 - 2021)



Project Introduction

In the coming decades NASA will launch missions to explore Ocean Worlds in search of conditions for life in the outer Solar System. In addition, landed mission concepts to study rocky bodies (the Moon, Mars, Venus and asteroids) are likely to be proposed. Seismometers are a common threshold instrument to most landed mission concepts, as they are the most efficient and proven tool to explore a planetary body's interior. Yet, since 1976 (Viking 2) no seismometer has been included in any of NASA's lander or rover missions. The main reason for this lies in the complexities in launching, landing, and emplacing intricate, highly sensitive, and delicate seismometers on extra-terrestrial bodies. This fact was highlighted by the complexities encountered by the InSight mission that will launch in May of 2018 (originally planned for 2016). To enable a simple implementation of geophysical exploration of deep planetary interiors in future missions NASA is in dire need for a small, robust, yet sufficiently sensitive seismometer that can be realized in multiple mission architectures. Currently, high-performance seismology is dominated by large, pendulous mass, instruments. Micro Electro-Mechanical System (MEMS) based seismometers offer the advantages of small volume and mass, low power, and reduced cost through batch fabrication; however, MEMS seismometers have traditionally suffered from lower performance. The sensitivity of a resonant vibratory sensor is limited by its thermal mechanical noise floor. A seismometer's noise floor is minimized by maximizing the resonator MTQ product (i.e. Mass x Period x Quality factor). Thus, high sensitivity is usually achieved by using a large proof mass and a very soft suspension system; this combination makes for a large, fragile instrument. A frequency tuning technique commonly used for MEMS resonators is to apply a voltage across a capacitor spanning the length of the spring, resulting in electrostatic spring softening. Increasing this voltage results in electrostatic frequency nulling (i.e. large T), enabling high sensitivity with a reduced proof mass. This has been demonstrated in the macro cryo-seismometer being developed by the University of Maryland and JPL. However, utilization of this technique is something that has not been exploited at micro length scales, but is a natural fit, as very small capacitive gaps can be micro machined in, substantially reducing the high voltages needed at macro length scales to exploit the effect. The objective of the proposed effort is to utilize electrostatic spring softening to develop a state of the art MEMS seismometer, unique in the ability to deliver broad-band sensitivity ($\sim 1\text{ng/rt-Hz}$ at 0.1-100Hz). High shock tolerance is easily achieved with a smaller proof mass by caging it. Furthermore, with the smaller proof mass, increase of the sensor bandwidth through negative force feedback can be accomplished capacitively, instead of inductively as utilized by macro seismometers; thus, the sensor becomes easier fabricate, is of homogenous construction (i.e. silicon with no metallic magnetic coils), and thus able to tolerate extremes in temperatures (e.g. -160C for Europa to 460C for Venus). Finally, the resonator quality factor will be maximized through construction out silicon, a material with low thermoelastic damping (i.e. low intrinsic losses), and the sensor will be



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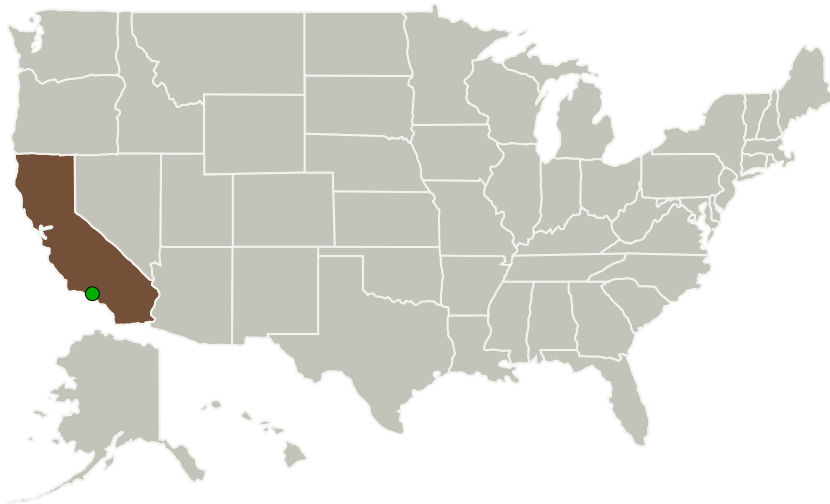


vacuum packaged in a COTS leadless chip carrier. This will be a compact sensor, easily incorporated into any lander with minimal impact to spacecraft size, weight and power; this device would also enable the low-cost deployment of a seismic network through the use of penetrators. Enabling the integration of a small sensitive seismometer onto future rovers, soft and hard landers, as well as onto impactors, will add a valuable geophysical facet to most future planetary surface missions without the complexity and associated costs that a dedicated geophysical mission demands.

Anticipated Benefits

3. Benefit to NASA Unfunded & Planned Missions: Through this project a compact, extreme environment compatible, shock tolerant, yet sensitive MEMS seismometer will be developed. Such a sensor will be deployable on future soft landers, rough landers, and even penetrators, enabling seismic science to be performed from any landed platform.

Primary U.S. Work Locations and Key Partners



Organizations Performing Work	Role	Type	Location
California Institute of Technology(CalTech)	Lead Organization	Academia	Pasadena, California
● Jet Propulsion Laboratory(JPL)	Supporting Organization	NASA Center	Pasadena, California

Organizational Responsibility

Responsible Mission Directorate:

Science Mission Directorate (SMD)

Lead Organization:

California Institute of Technology (CalTech)

Responsible Program:

Planetary Instrument Concepts for the Advancement of Solar System Observations

Project Management

Program Director:

Carolyn R Mercer

Program Manager:

Haris Riris

Principal Investigator:

Karl Y Yee

Co-Investigators:Karen R Piggee
Steve Vance
Sharon Kedar
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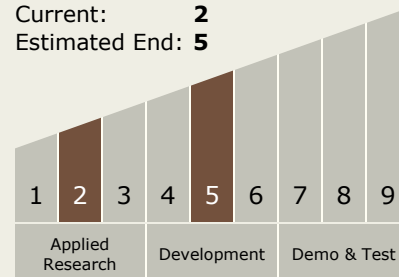


Primary U.S. Work Locations

California

Technology Maturity (TRL)

Start: 2
Current: 2
Estimated End: 5



Technology Areas

Primary:

- TX08 Sensors and Instruments
 - └ TX08.3 In-Situ Instruments and Sensors
 - └ TX08.3.4 Environment Sensors

Target Destination

Others Inside the Solar System